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(54) Optical position encoder arrangement

(57) An optical position encoder 1 uses a number of individual tracks 51—53. The optical sensors 30—35 are positioned remotely from the encoder disc and to avoid the need for a large number of individual light paths between the encoder disc and the sensors, a single optical fibre 15 is used in which the light is frequency multiplexed. The frequency multiplexing takes the form of a number of narrow band colours 21—26 which are selectively reflected from the disc preferably by holographic reflectors 2, further reflectors 17 being used to separate the transmitted light into its constituent wavelengths.

A process for obtaining the holographic reflectors is described. The concave reflector of Fig. 4 is obtained by illuminating 64 a metal ball 61 in contact with sensitised gelatine film 62 on a glass plate 63.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

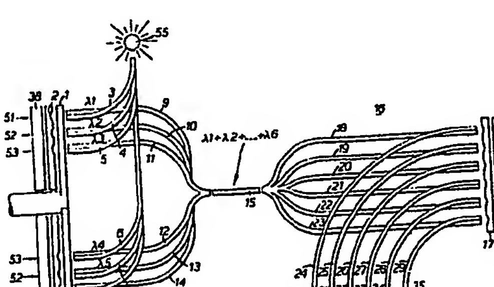
FIG.1.

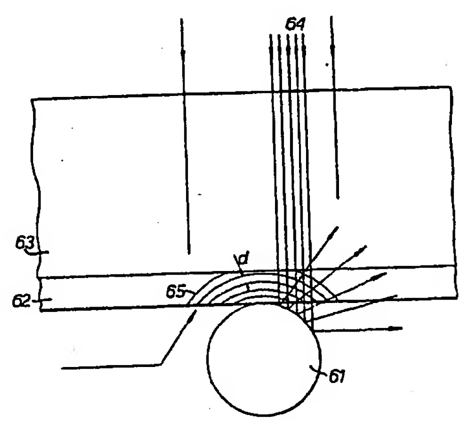

FIG. 4.

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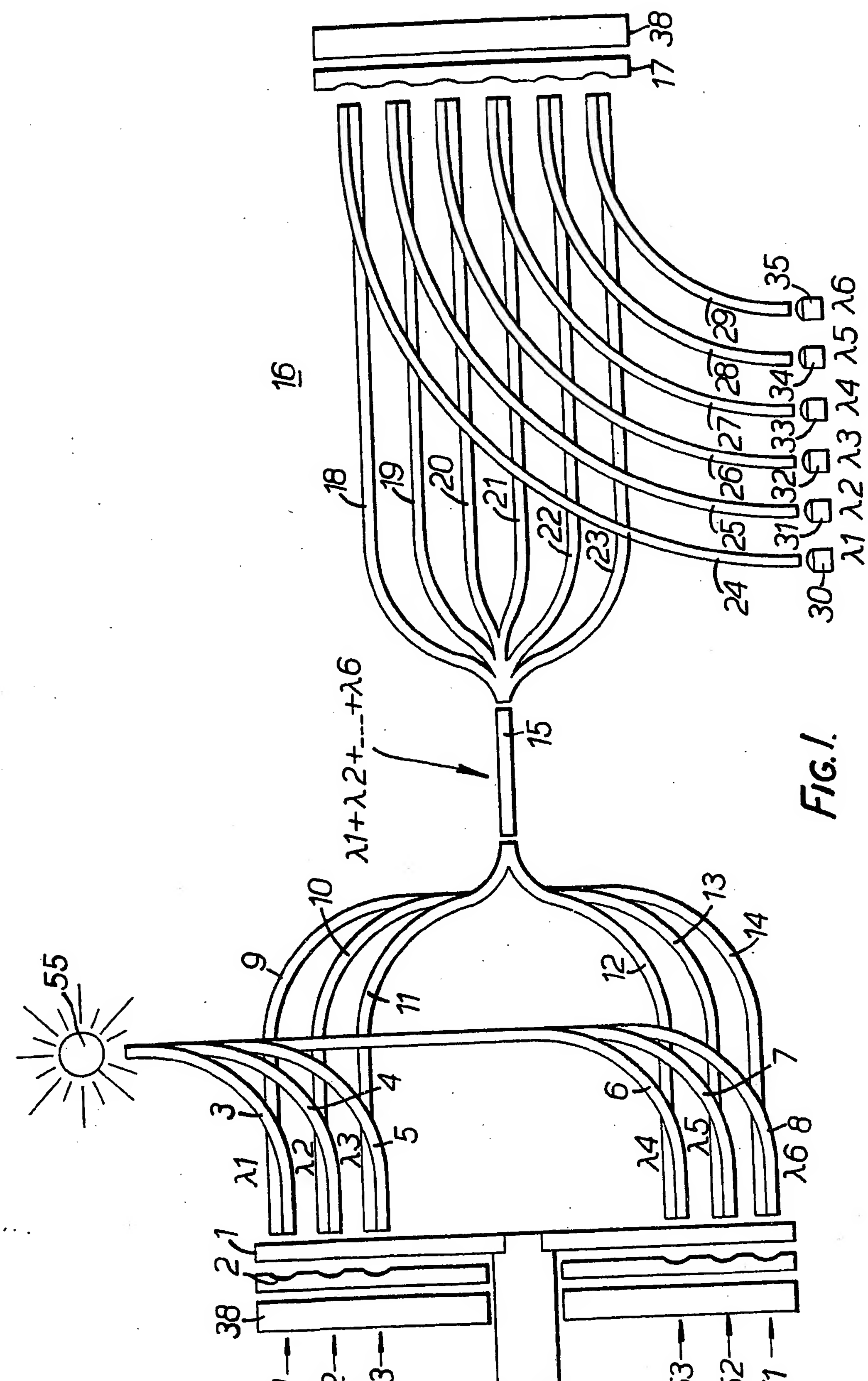
55
λ1+λ2+...+λ6
16
λ1 λ2 λ3 λ4 λ5 λ6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 38 51 52 53

FIG. 1.

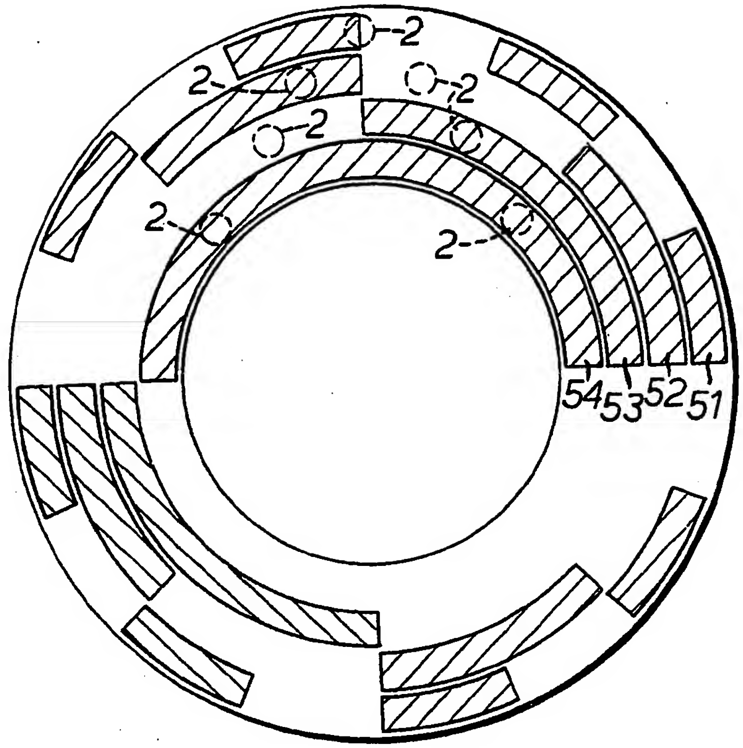

FIG.2.

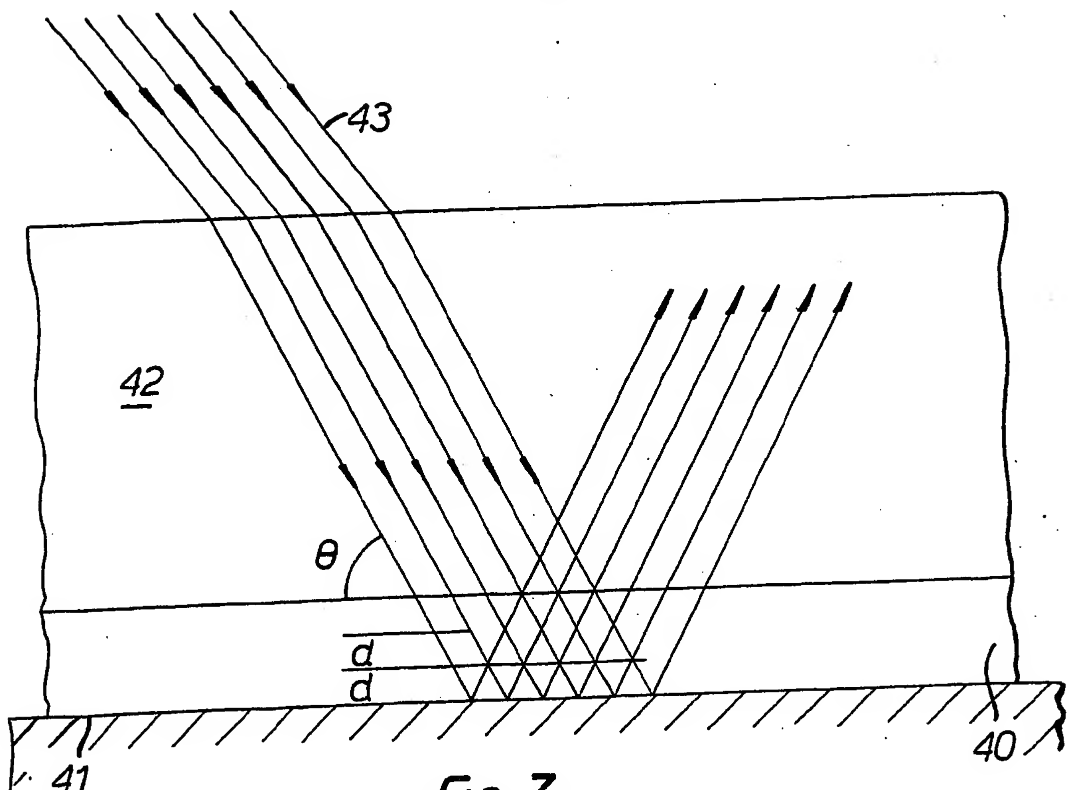

FIG.3.

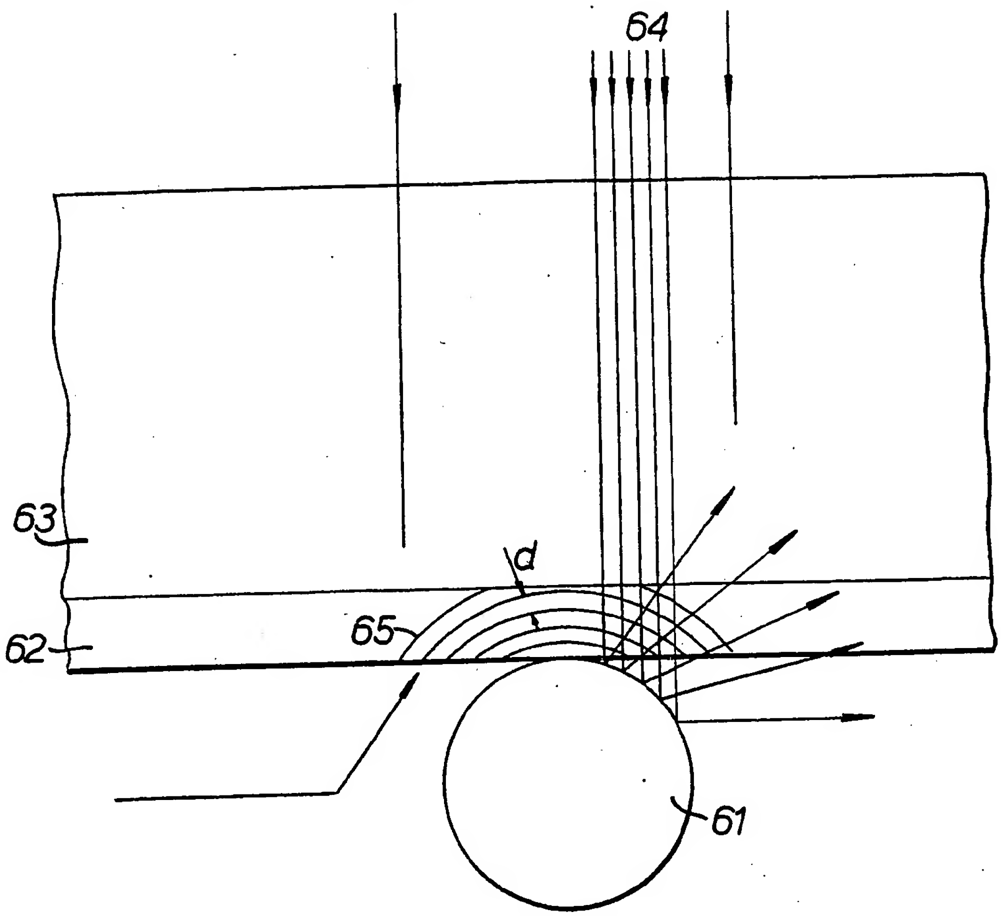

FIG. 4.

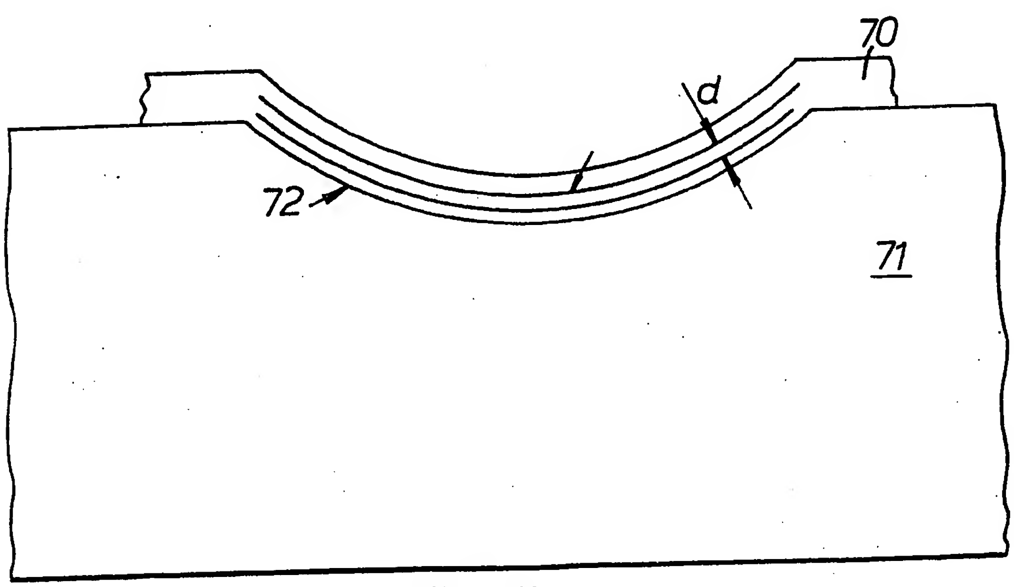

FIG. 5.

SPECIFICATION

Optical position encoder arrangement

This invention relates to optical position encoder arrangements. Arrangements of this kind include an optical pattern which is movable relative to an optical sensor and the nature of the optical pattern is such that its position relative to the sensor can be determined to a high degree of accuracy.

Encoder arrangements of this kind are increasingly being used to provide an accurate indication of the position of movable members and in order to provide a sufficiently precise indication of position, it may be necessary to provide several optical patterns of differing resolution. For example a shaft encoder which is arranged to determine unambiguously the absolute angular position of a rotatable shaft may need as many as twelve concentric optical tracks. Where the encoder itself is located remotely from photo-sensitive devices, it is necessary to conduct light to them via light guides, which may conveniently take the form of optical fibres. Such an arrangement can result in the need to provide many separate optical fibres, which can be excessively cumbersome or expensive. Additionally, the need to provide optical couplers between adjacent sections of optical fibres can result in unacceptably impracticable arrangements.

The present invention seeks to provide an improved optical position encoder in which this disadvantage is reduced.

According to this invention an optical position encoder arrangement includes a position sensing head having a plurality of optical sensing positions each arranged to determine the position of a movable optical mask in relation to optical receiving means, each optical receiving means being associated with a reflecting surface from which it receives light via the optical mask, the reflecting surfaces being illuminated with broad band light and being arranged to reflect light in a narrow band which is of a different predetermined colour for different reflecting surfaces, and means for combining different colours for transmission over a common light path.

All colours may be combined for transmission over a single light path, but if many colours are present it may be more convenient to combine small numbers of different colours for transmission over two or more separate light paths. In either case, significantly fewer light paths are required than there are different colours.

The combined colours are sent to a receiver unit arranged to detect the intensity of each colour present, since the position of the movable optical masks is determined as a measure of the variation in intensity of each colour.

Although a plurality of colour sensitive photodetectors could be used at the receiver unit, preferably instead the combined colours are separated into their separate original colours by means of further narrow band colour selective reflecting surfaces.

Preferably the reflecting surfaces are holographic reflectors arranged to reflect light of a very narrow frequency band. The reflecting surfaces are preferably constituted by a material which is not opaque and which contains variations in refractive index throughout the thickness of a surface layer. These variations are arranged to cause constructive interference in a reflected direction of light having a predetermined colour (i.e. predetermined wavelength).

The reflecting surfaces may be planar reflectors or instead they may be concave reflectors. Where the latter form of reflector forms part of the position sensing head, preferably the optical masks are arranged to pass through the centre of curvature of the concave reflectors. However, difficulties may be encountered in producing holographic colour reflectors which are not of a planar form and in general it is expected that they will possess a wider frequency response, but methods of making curved holographic colour reflectors are subsequently described herein. So that colours relating to as many different optical tracks as possible can be sent along a single optical light guide, it is clearly desirable that each colour shall possess the narrowest possible bandwidth. In view of this, each reflecting surface may be flat and is then provided with a lens which brings reflected light to a focus in the plane of the optical masks in the case of the position sensing head, and to a focus in the plane of optical receiving surfaces associated with wide band photosensors in the case of the receiver unit.

The invention is further described by way of example with reference to the accompanying drawings which illustrate in diagrammatic form an optical position encoder arrangement in accordance with the present invention and in which;

Figure 1 shows a schematic layout representing the whole encoder,

Figure 2 shows part of the position sensing head, and

Figures 3, 4 and 5 are explanatory diagrams relating to the production of holographic reflectors.

Referring to Figures 1 and 2, a position encoder arrangement is shown in which the position of a rotatable disc 1 is determined very accurately relative to a stationary disc 2. In practice, the disc 1 carries a number of concentric tracks 51 to 54 each of which is in the form of an opaque optical mask carried by a transparent substrate. The position of the optical masks relative to the fixed disc 2 can be determined with great accuracy and thus the position of the rotatable disc 1 can be known. Frequently the position encoder arrangement is located in a very remote or unaccessible position. Such a situation exists in aircraft where position encoding arrangements are used to determine and monitor the angular position of flaps on the aircraft wing, for example. The aircraft wing may experience an extremely hostile environment in which the normal

temperature limits set for the operation of electronic circuits can be greatly exceeded. It is desirable to locate the electronic circuits in a position which is readily accessible within the aircraft and which does not experience great extremes of temperature. For this reason an optical path is provided from the electronic circuits of the position encoder arrangement itself and it is necessary for the optical path to pass through a number of fixed aircraft bulk-heads. At each bulk-head, it is necessary to provide an optical coupler so that the optical information which is indicative of the angular position of the optical position encoder is not degraded. Such an arrangement is satisfactory so long as only a single optical path is provided. However, in order to provide the angular position with a sufficient degree of accuracy, it is usually necessary for the optical encoder to possess a number of separate tracks such as tracks 51 to 54 of differing resolution, and in practice twelve or thirteen optical tracks may be needed.

Figure 2 illustrates an optical encoder disc in which only four concentric tracks 51, 52, 53 and 54 are shown, although in practice the additional tracks would be needed to provide sufficient accuracy and resolution. A typical figure is twelve concentric tracks and the resolution of the outermost optical track determines the precision with which the angular position can be determined, the inner tracks being used to resolve ambiguities which might otherwise arise in connection with the position of the outer track.

In accordance with the present invention, the position information relating to a number of tracks is passed over a single optical path and in Figure 1 optical information from all of the tracks is passed over a single optical path. The information relating to each track is then separated out into the appropriate channel by an optical receiving device which is colour selective.

Referring in more detail to Figure 1, a source 55 of white light is coupled via a plurality of individual optical fibres 3, 4, 5, 6, 7 and 8 to individual tracks 51, 52, 53 of the optical mask 1. It will be seen that each optical track receives two optical fibres. This can also be seen on Figure 2 and the use of two optical fibres per track enables the number of separate tracks to be minimised, whilst resolving ambiguities in the angular position which might otherwise arise. The white light from the source 55 is passed by the optical mask on to an optical reflecting surface 2 and the reflecting surface adjacent to each optical fibre 3 to 8 is arranged to reflect light which lies only in a very narrow part of the optical spectrum. The colours reflected in this way are arranged to be mutually exclusive so that the colour is indicative of that part of the reflector from which it is received. The reflected light is received by the receiving surfaces of further optical fibres 9 to 14 inclusive and combined for transmission with a single light path 15. The colours present in this combined optical path are subsequently identified in a receiver device 16, which contains reflecting surface 17 which is highly colour selective.

Thus the white light is applied to the reflecting surface 17 over optical fibres 18 to 23. inclusive and the individual colour components are reflected selectively by the reflecting surface 12 along further individual light fibres 24 to 29. Photosensitive devices 30 to 35 are provided as shown, which provide an output signal if any light is detected thereby.

The nature of the colour selective reflecting surfaces 2 and 17 is described in greater detail with reference to Figure 3. Each reflecting surface consists of an optically transparent material which is arranged to provide constructive reflection for light lying in a very narrow frequency band and in order to achieve a frequency band which is sufficiently narrow for the present application, a holographic reflection technique is used. Because the reflecting surfaces 2 and 17 are transparent, absorbing plates 38 are positioned behind them.

The method of manufacturing a holographic reflector having the necessary narrow band reflection characteristic is described with reference to Figure 3 in which a sensitised gelatine layer 40 is positioned in contact with a reflecting surface 41. The gelatine layer 40 is supported by one surface of a glass plate 42. The gelatine layer 40 is illuminated by a parallel beam of laser light 43 which is incident at the angle θ to the mirror. The angle θ determines the wavelength and hence the colour of the filter. The light reflected by the mirror passes through the gelatine layer 40 again, setting up standing waves within the layer and the intensity variation in the standing waves is converted into a corresponding variation in the refractive index of the gelatine layer by the development process.

The gelatine layer is initially sensitised by immersion in a solution of ammonium dichromate, which is typically 5% by weight concentration. Excess solution is allowed to drain from the gelatine layer which is then dried in air at about 40% relative humidity for up to two hours. The gelatine layer is then exposed to the laser beam, which typically may be obtained from an argon ion laser having a wavelength of 488 nanometres or 514 nanometres. A typical exposure level is about 300 mJ/cm² with light having a wavelength of 514 nanometres. It is the angle at which the gelatine layer is exposed to the argon ion laser beam which determines the ultimate reflection characteristic of the layer. The layer is then processed by washing it in running water at about 20°C for ten minutes after which it is immersed in a 50% mixture of isopropyl alcohol, (IPA) and water for three minutes, and then subsequently in pure IPA for a further three minutes after which excess IPA is removed using an absorbent lens tissue. The gelatine layer is subsequently dried and baked in a warm oven at about 70°C for about ten to fifteen minutes. This process produces variations in the refractive index of the gelatine layer which result in constructive interference when the gelatine layer is illuminated by wavelengths of the appropriate value. The

value *d* shown in Figure 3 is related to the wavelength λ of reflected light by the expression

$$d = \frac{\lambda}{2 \sin \theta}.$$

Thus by illuminating the reflectors for each different photosensor at a different angle θ, reflectors which reflect different colours are produced.

Although Figures 1 and 2 represent holographic reflectors which are concave so that they not only reflect a particular colour, but bring it to a focus, the colour selectively may be improved by using planar holographic reflectors, as shown in Figure 3. In such a case a convergent lens is located between the holographic reflector and the ends of the optical fibres so that the reflected light is brought to a focus at the image receiving surfaces of the optical fibres.

The use of concave holographic reflectors which are colour selective would result in a simpler and more compact optical arrangement and methods of producing such reflectors are illustrated with reference to Figures 4 and 5. With reference to Figure 4, a highly polished metal ball 61, which could be of the type used in ball bearings is placed on contact with a sensitised gelatine film 62, which is formed on the surface of a flat glass plate 63. The ball is then illuminated by a parallel beam of laser light represented by lines 64 and the light reflected by the ball is passed back through the gelatine film 62, setting up curved standing waves 65. These standing waves are recorded as variations in the refractive index of the gelatine in a manner which is analogous to that described with reference to Figure 3. In use the effect of the hologram so formed is to reflect light of a narrow bandwidth to a focus as would a conventional concave reflector. The wavelength of the reflected light is determined by the pitch *d* of the standing waves.

In order to obtain curved holographic reflectors of this kind which reflect different wavelengths, a tunable dye laser could be used to expose the gelatine with the wavelength of the laser light being set to the required value for each reflector to produce the corresponding required value of *d*. Alternatively a single wavelength of a laser, such as an argon ion laser, could be used and the wavelength at which the holograph reflects can be adjusted by altering the amount of ammonium dichromate used to sensitise the gelatine. The ammonium dichromate has been previously referred to in connection with Figure 3 and it appears that the proportion of ammonium dichromate affects the effective refractive index of the gelatine.

A further method of producing a curved colour selective holographic reflector is to produce a flat hologram by the method described with reference to Figure 3 and to subsequently remove the gelatine layer from the substrate on which it was formed and to transfer it to a suitable concave surface which is provided with a blackened optically absorbing surface layer. This construction is illustrated in Figure 5 in which the gelatine layer 70 is mounted on an aluminium substrate 71 having a concave recess formed in its upper surface, with the absorbing surface layer 72 as shown. The curved standing waves are represented by the lines 73 — during the manufacturing step these cause the required variations in refractive index. The curved recesses can be accurately formed by pressing a very hard spherical ball bearing into the relatively soft surface of the aluminium. It is believed that this last mentioned method of making a curved holographic reflector will provide the best control over the colour selectivity of the reflector.

CLAIMS

1. An optical position encoder arrangement including a position sensing head having a plurality of optical sensing positions each arranged to determine the position of a movable optical mask in relation to optical receiving means, each optical receiving means being associated with a reflecting surface from which it receives light via the optical mask, the reflecting surfaces being illuminated with broad band light and being arranged to reflect light in a narrow band which is of a different predetermined colour for different reflecting surfaces, and means for combining different colours for transmission over a common light path.

2. An arrangement as claimed in claim 1 and wherein all colours are combined for transmission over a single light path.

3. An arrangement as claimed in claim 1 or 2 and wherein at a receiver unit the combined colours are separated into their separate original colours by means of further narrow band colour selective reflecting surfaces.

4. An arrangement as claimed in claim 1, 2 or 3 and wherein the reflecting surfaces are holographic reflectors arranged to reflect light of a very narrow frequency band.

5. An arrangement as claimed in claim 4 and wherein the holographic reflectors are concave reflectors.

6. An arrangement as claimed in claim 5 and wherein the optical masks are arranged to pass through the centre of curvature of the concave reflectors.

7. An arrangement as claimed in claim 4 and wherein the holographic reflectors are planar reflectors.

8. An arrangement as claimed in claim 7 and wherein each planar holographic reflector is provided with a lens which brings reflected light to a focus in the plane of the optical masks in the

case of the position sensing head, and to a focus in the plane of optical receiving surfaces associated with wide band photosensors in the case of the receiver unit.

9. An optical position encoder arrangement substantially as illustrated in and described with reference to Figures 1 and 2 of the accompanying drawings.

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